Space Technology Research Grants

Flow Quality Analysis of Shape Morphing Structures for Hypersonic Ground Testing Applications

Completed Technology Project (2013 - 2017)

Project Introduction

Background: Shape morphing, high temperature, ceramic structural materials are now becoming available and can revolutionize ground testing by providing dynamic flow capabilities to wind tunnels. The use of ceramic materials permits the wind tunnels to be run at high temperatures. Teledyne Scientific Company is currently developing shape-morphing ceramic hypersonic wind tunnels under an OSD Test & Evaluation/Science & Technology Program. The Applied Physics Group at Princeton University will be providing advisory support for computational modeling and technical support for experimental verification of free jet wind tunnel concepts. The NASA Space Technology Research Fellowship will fund the student's research into the modeling and verification of flows that are characteristic of generic shapes associated with these concepts. The key technology of the wind tunnel is a shape-morphing throat made from a woven ceramic material. The shape-morphing throat allows for the area ratio and thus Mach number to be varied. The particular design of the throat allows for both symmetric flows (where only the inviscid, variable Mach number core is important) and asymmetric flows (where boundary layer effects and shockwave interactions are important). Key Objectives: The goal of the proposed research program is to model computationally and verify experimentally the behavior of the flow through the contours and nozzle geometries associated with the shape-morphing ceramic hypersonic wind tunnel. For example, a shape morphing free jet wind tunnel might employ either a lenticular or quadricorn shaped throat to avoid sliding seals. Both symmetric and asymmetric flows will be investigated. In particular, answers to the following questions will be sought: I) How robust is the response of the flow to changes in throat shape or size, the expansion contour and the length of the expansion region? II) What is the quality of the flow structures resulting from changes in throat shape or size? III) How well do the models predict the flow properties and are there dynamic instabilities that occur due to pressure variations associated with the cusp shapes involved? IV) Is it possible to generate high quality asymmetric flows from an asymmetric opening? Methods/Techniques: The student will develop theoretical (analytical) and computational (computational fluid dynamics) models of the flow field downstream of the throat for purposes of predicting the flow field's response to changes in throat shape and size. The emphasis will be to answer questions I, II, III and IV from a modeling standpoint. Using the hypersonic wind tunnel facilities at Princeton University, the student will experimentally validate the theoretical and computational models by measuring the flow field with laser-based quantitative velocimetry techniques. The goal will be to answer questions I, II, III and IV from an experimental standpoint. It would also be highly desirable to test the shape-morphing throat at larger scales and higher enthalpies than possible with Princeton University's wind tunnels. This could be accomplished by testing different throat profiles in a wind tunnel such as the Arc-Heated Scramjet Test Facility at NASA Langley Research Center. Significance: The proposed research will demonstrate the ability of a shape-morphing ceramic hypersonic wind tunnel to provide high speed, high

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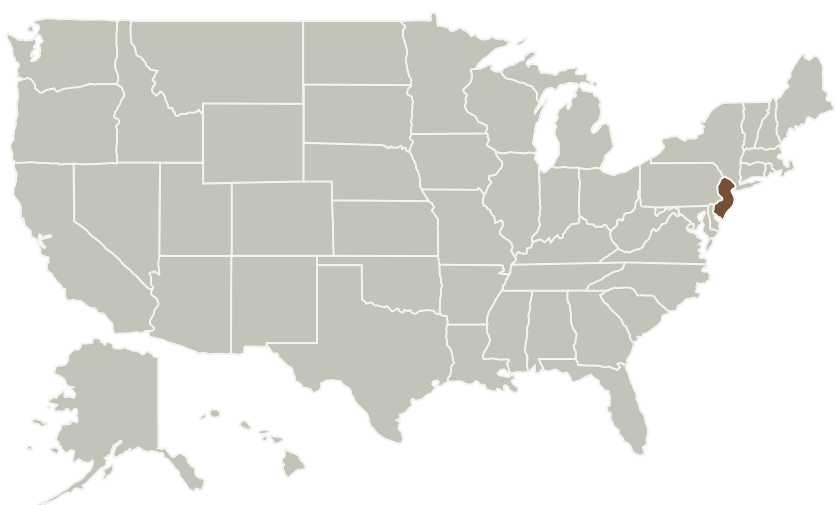
temperature, variable Mach number, symmetric and asymmetric flow of sufficient quality to test articles. Such a wind tunnel would allow for testing of combined cycle air breathing propulsion systems through their ramjet to scramjet mode transition. Furthermore, the wind tunnel would also offer high enthalpy, variable Mach number testing capability for non-scramjet applications such as reentry capsules, delta wings and missiles. In general, the shape-morphing ceramic wind tunnel is expected to lead to enhanced capability for ground based test centers.

Anticipated Benefits

The proposed research will demonstrate the ability of a shape-morphing ceramic hypersonic wind tunnel to provide high speed, high temperature, variable Mach number, symmetric and asymmetric flow of sufficient quality to test articles. Such a wind tunnel would allow for testing of combined cycle air breathing propulsion systems through their ramjet to scramjet mode transition. Furthermore, the wind tunnel would also offer high enthalpy, variable Mach number testing capability for non-scramjet applications such as reentry capsules, delta wings and missiles. In general, the shape-morphing ceramic wind tunnel is expected to lead to enhanced capability for ground based test centers.

Primary U.S. Work Locations and Key Partners



Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Princeton University

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

Richard C Miles

Co-Investigator:

Christopher J Peters

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Organizations Performing Work	Role	Type	Location
Princeton University	Lead Organization	Academia	Princeton, New Jersey

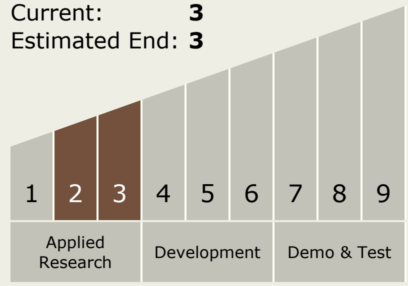
Primary U.S. Work Locations
New Jersey

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**



Technology Areas

Primary:

- TX15 Flight Vehicle Systems
  └ TX15.1 Aerosciences
    └ TX15.1.8 Ground and Flight Test Technologies

Target Destinations

Earth, Foundational Knowledge